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NASA TECHNICAL TRANSLATION

NASA TT F-15,294

THE ROLE PLAYED BY PARADOXICAL SLEEP IN MEMORY RETENTION

K. Leonhard and B. Roth

Translation of "Aufgabe des Paradoxen Schlafes in der Erhaltung des Gedaechtnisses," *Weinzeit fur Nervenheilkunde*, Vol. 30, 1972, pp. 46-57.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 FEBRUARY 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F-15,294	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle THE ROLE PLAYED BY PARADOXICAL SLEEP IN MEMORY RETENTION		5. Report Date February 1974 6. Performing Organization Code
7. Author(s) K. Leonhard and B. Roth		8. Performing Organization Report No. 10. Work Unit No.
9. Performing Organization Name and Address Techtran Corporation P.O. Box 729, Glen Burnie, Maryland 21061		11. Contract or Grant No. NASw-2485 13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Aufgabe des Paradoxen Schlafes in der Erhaltung des Gedaechtnisses," *Weinzeit fur Nervenheilkunde*, Vol. 30, 1972, pp. 46-57

16. Abstract

Recent experimental investigations make it likely that the REM phases of sleep serve to keep the memory efficient. This seems to confirm the interpretation formulated by one of the authors some years ago regarding dreams. If experiences are to be retained in the memory, they must be "activated" from time to time. When awake we would renew only what seems to be logically important at the time; other experiences would be quickly forgotten. In dreams however, according to the laws of thought association and picture return, both of which are described in detail, everything that we have ever experienced returns. This seems to be due to an independent activity of the nervous system by which it maintains its function.

17. Key Words (Selected by Author(s))	18. Distribution Statement		
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages ~~14~~ 16	22. Price 3.00

NASA-HQ

THE ROLE PLAYED BY PARADOXICAL SLEEP IN MEMORY RETENTION

K. Leonhard and B. Roth[1]

1. Neurophysiological Viewpoint (Roth)

Sleep research has made great strides over the last 25 years. One of the /46* most important steps in this direction is doubtless the discovery of paradoxical sleep and the differentiation between synchronous and paradoxical sleep phases.

Aserinksy and Kleitman (1953, 1955) and Dement and Kleitman (1957) discovered the relationship between dreaming and the paradoxical sleep phase. Experimental subjects who were wakened during paradoxical sleep almost always reported that they had been dreaming. The dependence of dreams on the paradoxical sleep phase was later generally confirmed.

With regard to synchronous sleep, it was originally thought that people dreamed either not at all or very seldom during this phase. Thus, Dement (1955), for example, writes of his subjects that dreams were reported in paradoxical sleep in 88% of all cases, but not even once in synchronous sleep.

Later, however, a number of authors reported dreams even during synchronous sleep, although much more rarely than in paradoxical sleep. As Berger (1969) correctly states, a great deal depends on the definition or criteria of dreams. If we call "dreams" only episodes with vivid, multisensory, but particularly visual and often colored perceptions accompanied by sharply-defined affective components, in which the dreamer usually plays an active role, and which are usually bizarre and conflict with logic, then we find dreams almost exclusively in paradoxical sleep and only infrequently in synchronous sleep. However, if we also call "dreams" episodes which are rather fragments of more or less

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*Numbers in the margin indicate pagination in the foreign text.

logical thinking, then we find them relatively frequently in synchronous sleep also. Roth and Bruhova (1969) divided dreams into two categories according to the above-mentioned criteria: vivid dreams, and vague, indeterminate dreams. In /47 the paradoxical sleep phase they observed dreams in 97.4% of all cases, of which 79% were vivid dreams and 18.4% indeterminate dreams. In the synchronous sleep phase dreams occurred in 34% of all cases, broken down into 10.2% vivid dreams and 23.8% indeterminate dreams. These results may be summarized by saying that real (vivid) dreams occur very frequently in paradoxical sleep and rather seldom in synchronous sleep. A certain psychic activity, which differs from the above-mentioned vivid dreams, can however also occur in synchronous sleep, especially in its light stages.

Although sleep research has turned up many new findings, especially those relating to the neurophysiological mechanisms of sleep, at present we still know very little about just why we sleep. As Moruzzi (1965) stresses, we are dealing not just with recuperation of the entire organism, of which we can easily convince ourselves when we spend a whole night in bed, quiet and relaxed, but without sleep. Probably recuperation of the brain is principally involved. However we must point out that the recuperation cycle of the individual nerve cells, which serve to transmit the train of impulses across the nerves and synapses, lasts only a few milliseconds and thus cannot account for the necessity of sleep lasting several hours. Certain neurons, e.g., the cells of the vasomotor center, of the vagal cardioinhibitory center, and of the respiratory center, are active continuously. Microphysiological studies, in connection with recording the activity of individual nerve cells, have shown no overall reduction in brain cell activity during sleep. We can rather say that their activity pattern is different in sleep and in waking (Evarts, 1965).

Many theories have been advanced as to the biological purpose of sleep. In our view, Moruzzi's theory (1965), according to which sleep is necessary for memory mechanisms, is of great significance.

As Moruzzi writes (1965, 1966), quite a different kind of recuperation takes place in sleep than the recuperation of the familiar synaptic transmission of stimuli. It is a long-lasting process of recovery with quite a different kind of activity. Memory, formation of conditioned reflexes, and all

phenomena pertaining to "higher" nerve function, are accompanied by plastic processes in the central nervous system which, according to Moruzzi, take place exclusively or predominantly in the waking state. Sleep could serve for recuperation of this plastic activity. The non-specific subcortical activation and inhibition structures, particularly the ascending activating reticular system and the bulbopontine synchronization center have the purpose of synchronizing the activity and, in particular, the recuperation of the above-mentioned structures or systems. If this were not so, the various cortical cells and /48
their associations would rest independently of one another, which would result in continuous "half-sleep," incompatible with survival of the species. In another paper on this subject, Moruzzi (1965) writes that it may be assumed that during the complex plastic processes necessary for learning, memory, and other functions, termed as a group as higher nervous activity, there is an accumulation of certain substances in the central nervous system which takes several hours to remove. As Moruzzi emphasizes, children receive many new impressions and engrams, and therefore sleep a great deal, while old people are no longer capable of learning and remembering very many new items, and consequently sleep little. In Moruzzi's view, certain synapses are of decisive significance for learning and memory, since the requisite plastic processes take place in these very synapses. Therefore, as Moruzzi states, we sleep so that the "learning synapses" can recover. The basis of these plastic processes is macromolecular alterations in the neurons.

In the discussion on this paper, presented at a symposium at the Pontifical Academy in Rome, Eccles (1966) emphasized that this was a "fascinating," original, and very fruitful hypothesis.

At another symposium (Zurich, 1964) Evarts (1965) explained in a discussion with Moruzzi that the vivid dream episodes usually leave no lasting trace behind them in the memory, with the exception of those cases in which the dreamer awakes immediately after the dream. From this Evarts concludes that the neuron discharges, necessary for direct perception, are retained in sleep, while the process necessary for consolidation of the memory trace is absent in sleep.

An important contribution was made by Hyden and Lange (1965). By careful microchemical investigations, they showed that in sleep the activity of the

enzyme succinoxydase is stepped up in the neurons of the reticular formation of the distal brain stem, while it is diminished in the neighboring glia cells. In the wakeful state this situation is reversed. Enzyme activity in the nerve cells is three times as intense in sleep as in waking. The changes described could be connected with the above-mentioned plastic processes and with their recovery.

Vitale-Neugebauer et al. (1970) investigated ribonucleic acid synthesis in the cerebral cortex during wakefulness and in synchronous and paradoxical sleep. They found significant differences in the results; the intensity of RNA synthesis was dependent on the functional state of the cerebral cortex, and particularly on the degree of synchronization or desynchronization of its activity. The authors hold the view that sleep can serve for long-lasting recuperation of the plastic activity of the brain or its programming. They emphasize that working and thinking capabilities are greater after sleep than before sleep. After sleep deprivation, efficiency decreases. The long duration of sleep in mammals could argue in favor of long-lasting processes of a macro- /49
molecular synthesis or for "supramolecular associations".

Another important question is the involvement of the synchronous as well as the paradoxical sleep phase in these processes. As is known, paradoxical sleep differs in all aspects from synchronous sleep, to the extent that many authors distinguish three basic modes of our existence: wakefulness, true sleep (meaning synchronous sleep), and dream sleep (meaning paradoxical sleep). It is therefore highly probable that their functions and biological meanings are different. Since when dreaming we very frequently see persons, animals, or objects known to us, and relive events which have actually happened, albeit often in distorted forms, there can be no doubt that memory traces are activated in sleep. If we think about the complex neurophysiological mechanisms of paradoxical sleep, which have been clarified to a great extent over the last fifteen years, we must conclude that it is undoubtedly an important function for the organism. Also, experiments with selective deprivation of the paradoxical sleep phase, after which the organism sees to it that the missed paradoxical sleep is made up, show the biological significance and importance of this mode of sleep for the organism. It follows that activation of engrams dating back

for various periods and stored in the brain's memory, during the dream phase of sleep, is absolutely essential and fulfills an important biological function.

Jouvet (1965) has put forward a similar view. Among other matters, he stresses that in the neonate period, in which the "plastic" processes of learning are particularly intensive, the percentage of paradoxical sleep in total sleep is significantly higher than in adults. In the newborn he finds up to 40% of total sleep, as opposed to 20-25% in adults. This fact argues, according to Jouvet, for a relationship between paradoxical sleep and the memory function. Another factor in favor of such a relationship, according to Jouvet, is the occurrence of a particular form of theta rhythm in the limbic system during paradoxical sleep. The relationship of such an activity during the waking state with the information storage processes in the central nervous system has already been discussed by Adey (1964).

Jouvet brought up the question of whether the "biological clock" located in the pons and triggering the paradoxical sleep mechanism, is also responsible for the complex biological processes with the aid of which, during sleep, we retain the memory of past experiences or, sometimes, lose it. Jouvet emphasizes that the paradoxical sleep phase would be a very appropriate time for this activity, as the disappearance of tonic muscular activity characteristic of paradoxical sleep makes it impossible for the organism, during dream sleep, to react myokinetically to the activity that has just taken place in the brain. /50 Jouvet ends his article with the hypothesis that paradoxical sleep, the biological basis of dreaming, could be an expression of a periodic function of information storage at the molecular level.

Jouvet's experiments (1965) with selective deprivation of paradoxical sleep show a 60% increase in paradoxical sleep as a percentage of total sleep at the end of deprivation. This value was never exceeded, however long sleep deprivation lasted. Jouvet thinks that a certain information threshold value exists, which brings into play the sleep mechanisms necessary for information processing.

A few further papers supply arguments for the great significance of paradoxical sleep for the storage and processing mechanisms of memory traces. Empson and Clark (1970) showed experimentally that persons deprived selectively

of paradoxical sleep during the night remembered much less in the morning of what they had learned the previous evening than a control group. The difference was statistically significant. Leconte and Bloch (1970) reported analogous results in experiments with rats. Pisani and Nigro (1970) also came to the conclusion that dreaming is "liberated mnemonic information".

The above-mentioned facts are at present not sufficient for convincing proof of the relationship between paradoxical sleep and memory mechanisms. However, this hypothesis does seem very close to the truth, at the present stage of our knowledge. There can be no doubt that memory traces are activated in dreaming and that dream sleep is indispensable for the organism. We therefore consider it probable that, during paradoxical sleep, processes occur which involve the reorganization and fixation of memory traces. On the other hand, it is possible that synchronous sleep, especially its deeper stages, serves for long-lasting recuperation of the above-mentioned plastic process.

2. Psychophysiological Observations (Leonhard)

Through the discovery of the paradoxical sleep stages, the question of the purpose of dreaming has once more become topical. When Jovanovic (1970) stated that REM phases no longer have any essential significance in human beings, but were "a vestige of phylo-ontogenetic development", this is improbable in view of their striking manifestations and their regular occurrence. The psychic changes occurring in persons deprived of the REM phases also confirm in a concrete manner that they must still possess a very real significance. This cannot lie on a higher psychic plane, since animals too, down to the lower mammals such as rats, show REM phases, and so probably experience in sleep something akin to human dreams. A connection with memory has not thus far been /51 shown experimentally, but does suggest itself. Recognition of this purpose of dreaming is nothing new: I tried some years ago (1951), when nothing was yet known about REM phases, to show on quite a different plane that dreaming serves for memory retention.

The precondition for retention of psychic events is the printing [sic], as we sometimes imagine it, of a "trace" or "engram", i.e., something is "engraved" on the nervous system and thus persists. This kind of notion is entirely unphysiological, for movement is an essential characteristic of life: something

experienced but not renewed is without doubt quickly forgotten. Moreover, no clear line can be drawn between the printing process and later retention, i.e., between short-term memory and long-term memory (more precise details are to be found in Whitty and Zangwill, 1966). What is not renewed is gradually lost, even if it was printed only a short while ago.

These being the circumstances, memory cannot be maintained by thinking in the waking state alone, for we experience so much that we do not think about for months or years, that nonetheless remains in the memory. This would not be possible if there was not another renewal of experience outside waking thought. Human thinking is conducted along logical lines; things that are irrelevant cannot come into the conscious mind. There is indeed "wool-gathering" where no strict order reigns, but here too we are usually guided by logical points of reference. In any case, we call to mind a great deal that we have not thought about for years while awake. It was this fact that was chiefly responsible for convincing me that dreaming plays an important role here. In dreaming the logical sequence of ideas disappears; pictures appear according to their own laws and are correspondingly renewed quite independently of how they fit into our logical thinking.

From my dream observations I find that there are two <u>laws</u> of dreaming. With optical-spatial dreams, which predominate over dreams in other sensory areas, we find that what recurs is what could not be perceived by the conscious mind on the previous day, but was evoked peripherally. I could adduce many examples and speak of a law of "thought association", which was already manifested from the observations of my predecessor dream researchers when they spoke of "unsettled remnants of the day". Episodes continually recur in dreams that were experienced on the previous day, but were in no way central -- merely fleeting and peripheral. This law was demonstrated with particular elegance in the experiments conducted some time ago by Poetzl (1917). He flashed pictures in front of experimental subjects so quickly that they could only pick up and reproduce them partially. The following night they dreamed not of what they had consciously seen, but of things also on the pictures but not registered /52 by the subjects. Poetzl's findings cannot be confirmed directly simply by observing dreams, as we know nothing of what we have not consciously registered,

but we can observe from any number of dreams that something is turning up that was only somewhere on the periphery the day before when we were awake. The dream images are sometimes so far removed from the central experience of the day, that we can speak of "peripheral dreams" (Vorbeitraeumen). At the recent (1966) International Congress of Psychiatry in Madrid, I gave many examples of this phenomena that I had collected over a few weeks. One of these examples is the following: in connection with my mimetic studies I was looking at photographs spread out in front of me on a folder. The following night I saw a number of halma men[2] in front of me on a folder, and swept them under the table. I saw nothing of the photographs in my dream.

According to the law of thought association, the dream brings to the conscious mind precisely what was left out of waking thought. The irrelevant, the matters of indifference which could not penetrate waking thought, recur in dreaming and are thus renewed.

What appears in dreams in this way is suggested to waking thought, and evoked peripherally. Many experiences however are so far removed from thought that they stimulate no association and are introduced in a dream. Accordingly, they would not be renewed were it not for a second law of dreaming: picture return. From many dream observations I was able to ascertain that the experiences of the day of which I was fully conscious returned after a certain period into my dreams. For optical-spatial dreams this period amounts to two to three weeks. We can confirm this when we change location: when we are on vacation and have not seen the people and objects that usually surround us for two to three weeks, they turn up in dreams. It has happened that, after this period, I have seen almost all my physician colleagues with whom I deal inside of one night. On the other hand, when one has been back from vacation for two or three weeks, one dreams of the people one saw on vacation. Although this period applies only to optical-spatial pictures, we can almost make a general formulation of the law of peripheral dreams, as dreams of this kind are in a clear majority. Dreams of colors are rare as opposed to dreams of shapes. Dreams of sounds in a clear form are even rarer, and dreams with sensory

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[2]"Halma" is a game similar to checkers - Translator's note.

perception of touch, cold, heat, taste, and smell almost never occur. The period between such sensations and their recurrence in dream is much shorter. Contrary to the law of peripheral dreaming, colors tend to recur in the night following the experience. Here we come to a dissociation between shape and color, which I have also observed on many occasions. A very recent example is the following: as we rarely see horses these days, I was looking with interest at a powerful horse of a fine silver-gray color. I had a peripheral dream /53 of the horse the next night: instead of the horse I saw a rabbit, but the rabbit had exactly the gray color that I had admired the day before in the horse.

One wonders why there is a direct relationship between the sensory area in which one dreams and the length of time that elapses until the impressions of the day reappear. If the pictures returned quickly, one could after all dream just as much or perhaps even more. This must have something to do with the fact that persistence in the sensory area with the long time delay is very great, here impressions die away only slowly and recur correspondingly late; this could then lead to the impressions, when they occur, prevailing over the other sensory areas. The parallelism between the breadth occupied by a sensory area in the dream and its degree of persistence is extremely clear if, for the latter concept, we consider not so much the intensity as the retention, i.e., the memory in this sensory area. Here we come to a very important statement: man's optical-spatial memory -- quite independently of differences between one individual and another -- is by far the best. His memory for colors and tactile processes is poor, and particularly poor for taste and smell impressions. In other words, according to the richness with which a man dreams in a sensory area, his memory in this area is good, less good, or poor. This parallel provides a confirmation for the hypothesis that dreaming aids memory.

The event that recurs in dreaming after a given period seems moreover to recur again at certain intervals: this is substantiated by the periodic dreams known to many people. Such periodicity cannot always be observed, but we must remember that man dreams an extraordinary amount, but remembers very little of his dreams when he wakes. The findings on REM phases show what an infinite quantity of experience a man must go through in sleep, although many people

claim that they do not dream at all. It should also be remembered that dream images are generally of extreme clarity only at their first appearance; as they are repeated they become paler unless -- according to the other law -- they are stimulated and activated by association. We can see another parallel: what one has just experienced must be strongly renewed if it is not to be forgotten, for the most recent experiences are most quickly lost when a memory lapse occurs. Events that have been stored for a long time in the memory are retained with less intensive renewal.

3. Discussion (Leonhard)

The statement should thus be formulated as follows: dreaming plays the role of continuously renewing as much as possible of human experience and thus retaining it in the memory. It is certain that people do not dream only in the REM phases, as many allege today. When a person has learned to observe himself when dropping off to sleep, he can often confirm directly that hypnagogic images pass into dreams, while REM phases do not occur in the hypnagogic period. REM sleep, however, is probably expressly intended for dreaming, while the other phases of sleep serve mainly for recuperation. /54

To be sure, this interpretation comes up against the fact that even newborne infants experience percentually more REM phases -- more so even than older people. Since the newborn infant has as yet received no impressions from the outside world, he can experience no graphic reiterations in the form of dreams. One may deduce from this that dreaming represents only a subjective sign of what is going on in the REM phases. This permits me to develop an interpretation supported by all observations. Probably, an independent activity of the nervous system occurs in the REM phases, an activity necessary to preserve its general functionality, in particular its memory. The activity of a waking person excludes many areas of his nervous system which would gradually become non-functional if not kept alive by independent activity. Hence we can understand why people deprived of REM phases experience not only weakness of memory but more generalized psychic disturbance.

The independent activity of the nervous system certainly does not take place in the sphere of psychic functions only, but in more profound areas too; otherwise the limitedness of waking experience would have adverse effects. For

example, the muscular system is strained in very different ways: one set of muscles can be kept active almost to the point of exhaustion while another set remains almost inactive. The muscular system adapts to strain by one set thickening, possibly to the point of becoming powerful, and the other set shrinking through inactivity and suffering from dysfunction. Here the nervous system behaves differently: it experiences no disuse atropy but retains its full capability, even when it is no longer involved in normal actions. We have found this indirectly from the fact that cerebral paralysis never causes total atrophy of the muscle, as do peripheral atrophies. When the spine cord is severed at the upper thoracic level the voluntary innervation to the legs is cut off, but their muscles atrophy no more than if they simply stopped being used. As long as the peripheral nerve is there, the muscle remains functional. To discard the hypothesis of reflex innervation we need only consider the case when a sensory nerve is cut off: only disuse atrophy occurs. Here the peripheral nerve, just like the muscle, is deprived of all normal activity but does not atrophy; on the contrary it sees to it that its associated muscles do not deteriorate, as would a severed nerve. Thus the nervous system has a general capability -- not just in the psychic sphere -- of keeping itself functional by its own action, and thereby preserving from damage dependent organs not utilized for a long time or incompletely utilized.

This probably also applies to the vegetative functions. With persistently /55
very unbalanced nutrition, for example, many gland parts lose their functions unless their associated secretory nerves remain functional by independent activity. This leads to an explanation for the remarkable fact that erections tend to occur in REM phases. Instead of the directed, focussed sexuality of the waking state, of varying intensity, it seems here that a diffuse independent activity of sexuality is taking place. With the erection this activity is outwardly visible, but no similar indications are available of independent activity of other vegetative functions. In the psychic field, on the other hand, we have inner indications (dreams, dream reports) that nervous episodes are occurring independently.

From these considerations, dreaming becomes a partial manifestation of a more general law. It appears that independent activity keeps the nervous

system functional, and is manifested in dreaming when people carry within themselves impressions from the outside. When dreaming, people perceive from the inside the part of activity in which outer events are reproduced, so that they remain vivid. The regular recurrence of impressions after certain periods is directly attributable to this independent activity. Dreams triggered by association, on the other hand, point to collaboration of wakeful thought such that the independent appearance of dream images calls forth unconscious or at least very fleeting stimuli. It is difficult to decide whether, especially in the psychic field, a special function is involved or whether the nervous system reacts generally to mild stimuli with increased independent activity. In the psychic field the law states that what is central in wakeful thought appears more often in dreams than something remote.

In this way still another function of dreaming is accomplished, namely the furthering of productive or even creative thoughts reported by many investigators. Novel ideas always lie near the boundaries of logic, only when they are grasped does one recognize their significance. Dreaming grasps such associative or only lightly stimulated thoughts, which can be shown to be creative. We will not enter into greater detail here.

It is not surprising that even animals have REM phases, for animals too need to remember. When it reaches a certain stage in its phylogeny, the animal has to learn a great deal if it is to survive. Although one finds REM phases in animals not thought to be capable of dreaming, they at least have a nervous system, to which is owed the capability of independent activity.

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Translated for the National Aeronautics and Space Administration under contract No. NASw-2485 by Techtran Corporation, P. O. Box 729, Glen Burnie, Maryland, 21061. Translator: Isabel Leonard.